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Rupture in a Collembola community structure from a *Quercus rotundifolia* Lam. forest due to the reafforestation with *Eucalyptus globulus* Labill.

J. P. Sousa and M. M. da Gama

Departamento de Zoologia e Centro de Sistemática e Ecologia, Universidade de Coimbra, 3049 Coimbra Codex, Portugal.

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Abstract

Here we compare Collembola populations from a *Quercus rotundifolia* forest and an *Eucalyptus globulus* plantation. The overall analysis of data (using both diversity and similarity measures) have shown clear signs of rupture on the structure of collembola populations, with the fauna associated with the *Quercus* stand being richer (in exclusive and preferential species) and more abundant than the one connected with the *Eucalyptus*. Data also reflects the faunal stratification between organic and mineral horizons, with the majority of species being associated with upper soil layers in detriment of mineral horizon. These disruptions may be related to profound alterations of habitat characteristics, particularly the frequent removal of shrub vegetation and leaf layer, result of the forestry practices connected with the preparations and management of the eucalyptus plantation.

Keywords: Collembola, holm-oak, eucalyptus, reafforestation, community structure.

Rupture dans la structure de la communauté des Collemboles d'une forêt à Quercus rotundifolia *Lam. due à un reboisement par* Eucalyptus globulus *Labill.*

Résumé

Les populations de Collemboles d'une forêt à *Quercus rotundifolia* et d'une plantation d'*Eucalyptus globulus* sont comparées. L'analyse globale des données (utilisant des mesures à la fois de diversité et de similarité) ont montré des signes évidents de rupture de la structure des populations de Collemboles, la faune associée au site à *Quercus* étant plus riche (en espèces exclusives et préférentielles) et plus abondante que celle peuplant le site à *Eucalyptus*. Les données reflètent également la stratification faunistique en horizons organique et minéral. Ces ruptures sont à mettre en relation avec des altérations profondes des caractéristiques du site, en particulier l'exportation fréquente de la strate arbustive et de la litière, résultant de pratiques forestières en vue de la préparation et de la gestion de la plantation d'eucalyptus.

Mots-clés : Collembola, chêne vert, *eucalyptus*, reboisement, structure de la communauté.

INTRODUCTION

During last decades, Portuguese autochthonous forests have been depleted in favour of exotic tree species, mainly the eucalyptus (*Eucalyptus globulus* Labill.). Exploited for commercial reasons, massive plantations of this species reach already an extension of 539 000 hectares. As an evergreen fast growing species, it can induce changes in soil processes and in the structure of soil biota associated with litter decomposition, leading to a perturbation of the equilibrium in soil system. Therefore, eucalyptus plantation may be considered a potential environmental problem.

Eucalyptus have been replacing mainly pine forests (*Pinus pinaster*, Aiton) and, to a lesser extent, the black and common oaks (*Quercus pyrenaica* Willd and *Q. robur* L.) in the northern part of the country, the holm-oak (*Q. rotundifolia* Lam.) in the inner

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centre and the cork-oak (*Q. suber* L.) in the south, all representatives of the ancient natural forests.

This study, a part of a broader research project [1], aims to compare the biodiversity and community structure of soil mesofauna between a *Q. rotundifolia* forest and an *E. globulus* plantation. Collembola, due to their representation in soil arthropod fauna and to their role in soil processes, has been used as indicators of ecological status of soils (Ponge and Prat, 1982; Arbea and Jordana, 1985) and so, selected as biological material for our purpose.

Other studies (Figueiredo *et al.*, 1985; Gama *et al.*, 1989, 1991), concerning the comparison of collembola populations in eucalyptus and natural forests (*P. pinaster* and *Q. suber*), have shown that there is a distinguished separation between fauna associated with the natural and the exotic tree species. In fact, eucalyptus seems to support a lower diversity and species richness than natural forests, which also tends to be richer in exclusive and preferential species. The study presented here confirms the above mentioned results in a general way.

MATERIAL AND METHODS

1. Study sites

Q rotundifolia and *E. globulus* stands were situated in the province of Castelo Branco, inner centre Portugal. Both located at an average altitude of 300 m and presenting an exposition ranging from N70°E to N175°E (holm-oak) and N100°E to N105°W (eucalyptus) and with slopes from 9% to 24% (holm-oak) and 10% to 30% (eucalyptus), they were characterized by a nutrient poor schistous soil type.

In terms of vegetation cover, holm-oak forest presented a dense shrub layer dominated by *Cistus ladanifer* L., *C. salvifolius* L. and *Lavandula stoechas* L. Oaks appeared both as mature trees (aged more than 30 years) and young plants, contributing to the thickness of the shrub layer. The entire site presented a constant leaf cover, particularly homogeneous bellow trees.

The soil on the eucalyptus stand presented intense signs of management (soil was heavily revolved and mixed), therefore with a scarce vegetation cover. Eucalyptus trees (aged about 10 years) were planted, in substitution of oak trees, in grooves opened along the altitude lines. In some sampling quadrats there was some accumulation of eucalyptus leaves and bark on those grooves.

The physical and chemical characterization of both sampling sites (*table* 1) shows that there is a distinguished difference between them. This could be related to the strong anthropogenic influence in the eucalyptus stand. The pressure caused by the preparation of the eucalyptus plantation (removal of the existing vegetation and groove formation) and its maintenance (regular cleaning and cutting) led to a decrease in vegetation cover and in standing stock biomass. This caused a decrease in humus horizon thickness, in moisture and nutrient content, therefore contributing to an impoverishment of the soil.

Table 1. – Physical and chemical characterization of study sites (mean ± SD). Samples were cumulated and means were compared by t-test.

	Q. rotundifolia	*E. globulus*	
Humus horiz. thickness (cm)	2.6 ±0.9	1.9 ±0.5	*
Soil pH	6.66±0.38	5.63±0.18	*
Soil temperature (°C)	12 ±1.4	14.2 ±2.3	*
% Water content (humus)	24.65±9.35	12.15±5.56	*
% Water content (soil)	17.48±5.55	14.9 ±5.21	n.s.
% Carbon (humus)	4.71±1.23	1.98±0.84	*
% Carbon (soil)	2.29±0.64	1.78±0.60	**
% Nitrogen (humus)	0.34±0.11	0.13±0.06	*
% Nitrogen (soil)	0.2 ±0.05	0.13±0.07	*
C/N (humus)	14.69±3.67	16.79±5.07	n.s.
C/N (soil)	11.77±3.36	15.73±5.02	**
% Org. matter (humus)	11.76±2.67	5.18±1.56	*
% Org. matter (soil)	6.37±1.23	4.81±1.04	*

* $p < 0.001$; ** $p < 0.05$; n.s. - non significant

2. Sampling, soil characterization and fauna extraction

Sampling was done in March 1992. At each stand 4 quadrats (8 m per 8 m) were selected at random and divided in 16 small squares (2 m per 2 m). Inside each quadrat, 4 squares were then randomly selected, making a total of 16 sampling squares per site. After a careful removal of the leaf layer, two samples (250 cc. each) were taken at different depths in each square, one in the organic horizon (designated by humus horizon or humus) and the other in the mineral horizon (designated by soil). Simultaneously, soil temperature and organic horizon thickness were measured. To catch epigeic fauna, a pitfall trap (a plastic vial of 2 cm of diameter) was placed at each sampling square for one week.

Fauna was extracted by means of Berlese-Tullgren funnels, sorted under binocular microscope and identified to species level under light microscope. After extraction, air-dried samples were gently crushed and sieved though a 2 mm sieve and four aliquots were separated for analysis. Water content was measured according Dewis and Freitas (1984) and was expressed in terms of percentage of water in relation to dry weight at 105°C. Organic matter content

[1] This study is included in a STEP-CE's research project named "Fluctuations of biodiversity patterns following reafforestation with indigenous *versus* exotic tree species".

was expressed as Ash Free Dry Weight and Carbon and Nitrogn contents were measured by Anne's and Kjeldahl's methods respectively (Dewis and Freitas, 1984). pH was measured in water (1:6 v/v) at 20°C.

3. Data analysis

Differences in community composition between both sites were evaluated by two different methodologies, using either diversity or similarity measures. In the first, species diversity, evenness and species richness were calculated for the different strata inside each site (samples were cumulated for each stratum), following Shannon-Weaver, Pielou and Margalef indices respectively (Magurran, 1991).

In the second group of analysis, the Bray-Curtis coefficient, selected by its robustness in analysing ecological data (Faith *et al.*, 1987), was used to measure similarity between holm-oak and eucalyptus samples. Prior to the analysis, data were transformed to $y_{ij} = \text{Log}(x_{ij} + 1)$. Two types of analytical procedures were performed using this coefficient:

1. With the need to associate statistical power to the comparative analysis of both communities, the average similarity of each stratum of the "control" group (holm-oak inter-sample similarity) was tested against the corresponding average similarity of the "treatment" group (holm-oak *vs* eucalyptus samples) by means of a t-test. For this analysis the 4 samples inside each quadrat were cumulated, making a total of 4 exprimental units per site. To achieve homoscedasticity of sample variances, an arcsin$\sqrt{}$ tranformation was performed in the similarity data before the t-test comparison.

2a. An agglomerative hierarchical clustering method was applied to the two similarity matrices resulting from the Bray-Curtis resemblance measure, in a way to achieve a graphical representation of the relations between strata (normal or Q mode analysis) and species (inverse or R mode analysis). To obtain the similarity matrices we grouped the total number of samples at each stratum, making 6 groups for 48 *taxa*.

2b. As a way to enhance the interpretation of results from the numerical classification, we have performed a post-clustering "nodal analysis" (Boech, 1977). This procedure relates normal to inverse analysis where groups of similar samples are related to groups of co-occurrence *taxa*. This is done using the ecological concepts of constancy and fidelity. Both were graded according to Boech (1977) and numerically expressed as:

- $C_{ij} = a_{ij}/(n_i\, n_j)$ for Constancy
- $F_{ij} = (a_{ij} \Sigma\, n_j)/(n_j \Sigma\, a_{ij})$ for Fidelity

where $\mathbf{a_{ij}}$ is the actual number of occurrences of members of species group **i** in the samples group **j** and the $\mathbf{n_i}$ and $\mathbf{n_j}$ are the numbers of entities in the respective groups. Constancy index has a maximum of 1 when all species occurred in all samples in the group and a minimum of 0 when none of the species occurred in that particular samples group. Fidelity values greater than 2 suggest strong "preference" of species in a group for a samples group and values lower than 1 suggest "avoidance" of the spatial habitat represented by the samples group or negative fidelity.

RESULTS

A total of 1958 specimens, distributed by 48 *taxa*, were identified. *Q. rotundifolia* community supports the highest abundance and variety of species of both sites, being represented by a total number of 1562 individuals and 43 *taxa* (*table* 2). By contrast, *E. globulus* community has only 396 specimens and 26 *taxa*.

The autochthonous site also have higher values of species diversity, species richness and evenness than the eucalyptus plantation (*table* 2). This superiority, common to both humus and mineral horizons and pitfall trap samples, may be related with site characteristics mentioned above, with holm-oak forest having the best ecological conditions for individuals needs, i.e., food and microhabitat availability.

Comparing the different strata on both sites, we can observe that organic layer tends to be richer than mineral horizon. Shannon-Weaver diversity values also tends to be higher in upper soil layers, specially in eucalyptus site. The holm-oak humus value seems to misfit this context. Its lower values, in relation to soil and pitfall trap values, is connected with an high abundance of *Brachystomella parvula* which led to a decrease in evenness, therefore in diversity.

Another clear sign of rupture on the structure of collembola community, caused by the substitution of autochthonous vegetation by eucalyptus, are the lower similarity values observed in the "treatment" groups of all strata when compared with the correspondent "control" groups (*fig.* 1). The values observed in

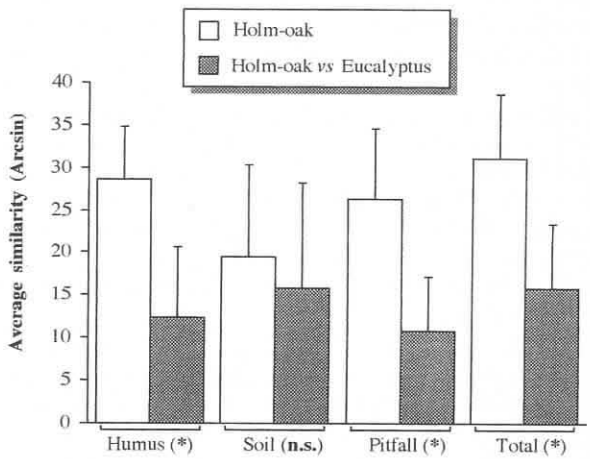

Figure 1. – Average similarities (± SD) on control (holm-oak) and treatment (holm-oak *vs* eucalyptus) groups for the different strata. Groups were compared by a t-test: "*" $p < 0.001$; n.s. non-significant.

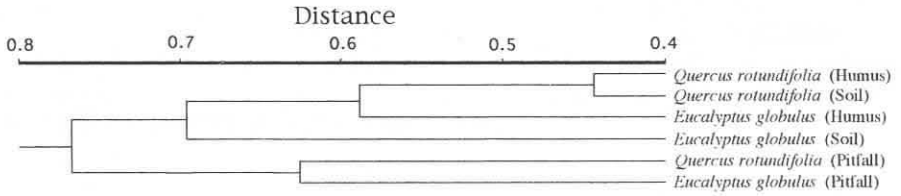

Figure 2. – Phenogram corresponding to the Q mode analysis based on Bray-Curtis distances.

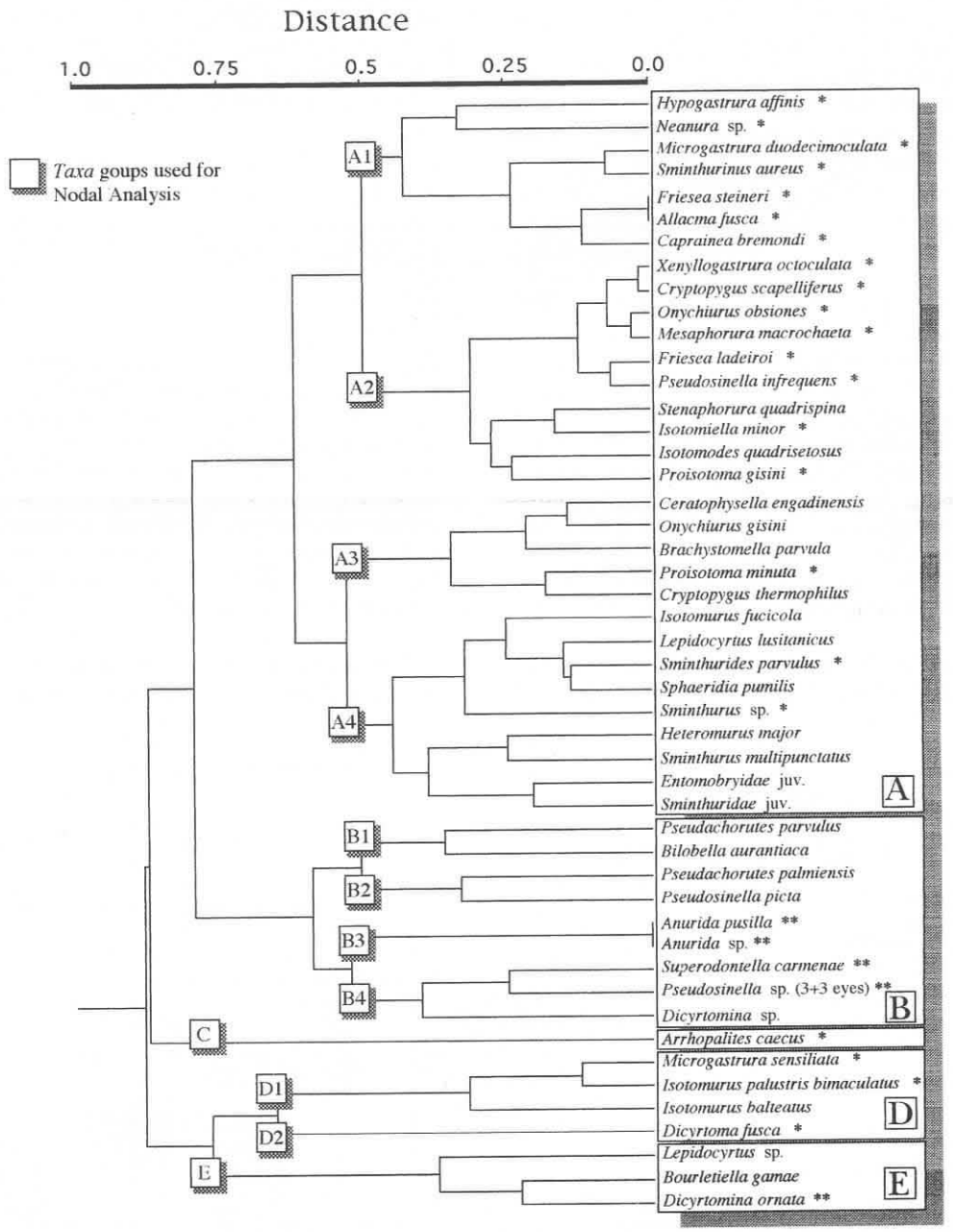

Figure 3. – Phenogram corresponding to the R mode analysis based on Bray-Curtis distances. "*" signs species occurring only in *Q. rotundifolia* site and "**" signs exclusive species of *E. globulus* site.

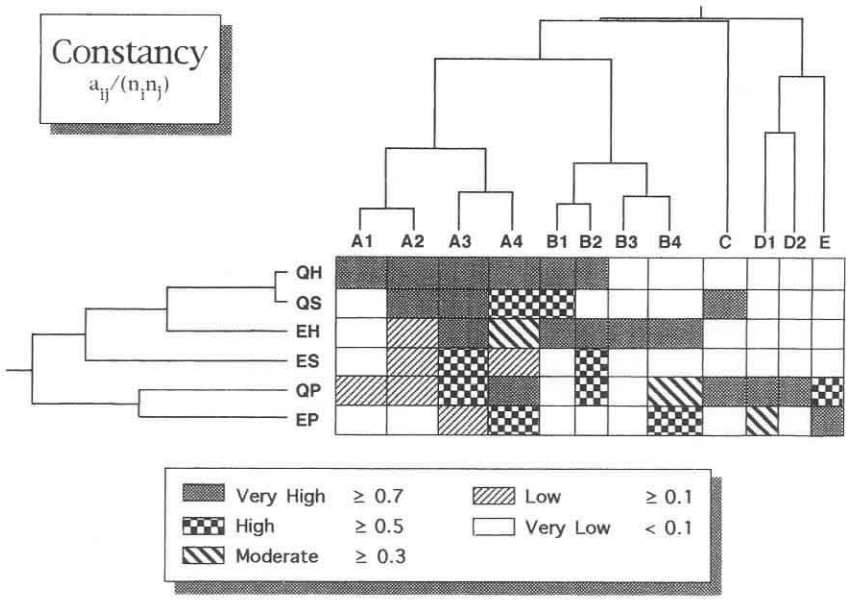

Figure 4. – Constancy values for post-clustering nodal analysis. Samples and species groups according to figures 2 and 3 respectively.

"controls" are all significantly higher ($p \ll 0.001$), with the exception of mineral horizon. The discrepancy, in terms of number of *taxa* and individuals found between both mineral horizons (*table* 2), could not compensate the great variability of similarity values found inside both "control" and "treatment" groups. Note in figure 1 that soil presents the highest SD values of all, which cause a small difference between means, leading to a decrease in the "t" value and to a non significant difference between both groups.

The phenogram of the Q analysis (*fig.* 2) also demonstrates the distance existing between both sites. Organic and mineral horizons at each site are related with each other, forming different groups, although the degree of similarity on holm-oak is higher than in eucalyptus. Pitfall traps are grouped together and relatively separated from the correspondent sites. This could be explained by the presence of several species (*Microgastrura sensiliata, Isotomurus palustris bimaculatus, I. balteatus, Dicyrtoma fusca, Lepidocyrtus* sp., *Bourletiella gamae* and *Dicyrtomina ornata*) that appeared exclusively in these samples.

The separation observed between both sites and the "isolation" of pitfall traps is also visible in

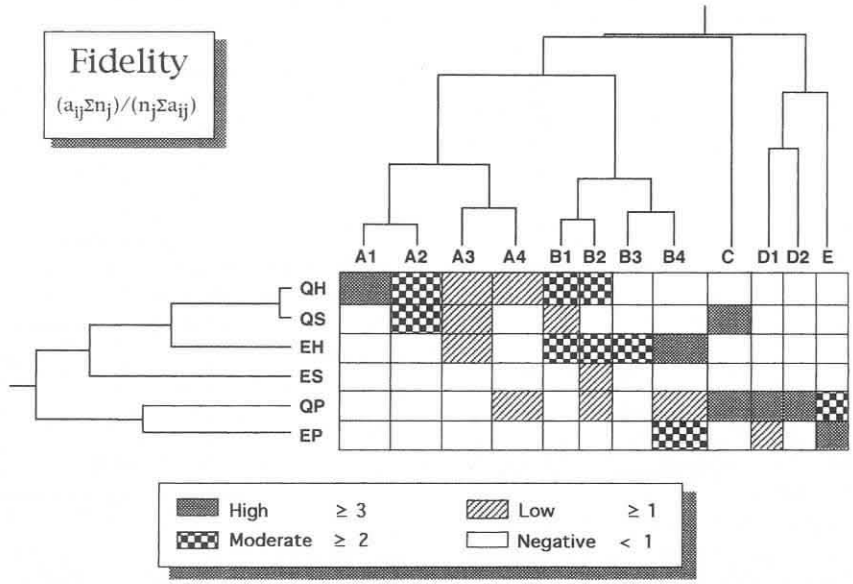

Figure 5. – Fidelity values for post-clustering nodal analysis. Samples and species groups according to figures 2 and 3 respectively.

the phenogram of the R analysis (*fig.* 3), where five groups can be distinguished. Two of them (groups A and B) comprehends the *taxa* exclusive or dominating in the *Q. rotundifolia* and *E. globulus* sites respectively. Other two represent the species that appeared exclusively in pitfall traps, either in holm-oak (group D) or eucalyptus (group E) sites. Group C is a single species group (*Arrhopalites caecus*) and is relatively isolated from the rest of the clusters, reason to be classified separately.

Group A, composed by 31 *taxa*, 18 of them being exclusive of holm-oak forest (signed by *), can be divided in four subgroups –A1 to A4– used in nodal analysis (*figs.* 4 and 5) and in which we can denote a gradient tendency. Subgroup A1 is composed by species found only in *Quercus* site and with exclusive preference for humus horizon (see constancy and fidelity values). Species group A2, although constant to almost strata, shows a moderate fidelity to holm-oak organic and mineral horizons. The low constancy of this group in eucalyptus humus and soil is due to the weak presence of *Stenaphorura quadrispina* and *Isotomodes quadrisetosus* in these horizons.

Subgroups A3 and A4 are constant to all strata, but show the highest values for holm-oak. Due to the large constancy spectrum, these groups of species present low fidelity values, nevertheless favorable to upper layers of holm-oak site (humus and pitfall traps). This bias to upper strata is demonstrated not only by presence data (nodal analysis is based on presence absence data), but also by abundance data, with some species being numerically dominant in the humus horizon.

Cluster B, composed of 9 species (with 4 of them being exclusive for eucalyptus site – signed with **), was also divided into four subgroups. Species groups B1 and B2 show high values of constancy for both *Q. rotundifolia* and *Eucalyptus* sites (*fig.* 4) and present a preference for humus layers (*fig.* 5). All species of subgroups B3 and B4, with the exception of *Dicyrtomina* sp., are exclusive of eucalyptus site and also present a clear preference for superficial layers (*fig.* 5).

Clusters D and E are composed by species occurring exclusively in pitfall samples, numerically dominant either in holm- oak (group D) or eucalyptus (group E).

DISCUSSION

The overall data analysis suggests that the reafforestation with *E. globulus* caused a rupture on the composition of collembolan populations. The fauna associated with *Q. rotundifolia* forest is much richer in species and number of individuals than that associated with *E. globulus*. In fact, diversity data (*table* 2) have higher values in all parameters for the former site than for the last one. Data on figure 1 also show that similarity between sites is lower than similarity of control groups, reflecting a statistical difference between communities of holm-oak and eucalyptus.

Multivariate cluster analysis also reflects a distinguished separation between both sites. Humus and mineral horizons of the same site tend to be grouped together, but pitfall samples make a different cluster. The diagram of the R analysis also shows this separation, with the formation of groups corresponding to those species associated most with humus and soil of each one of the sites and to pitfall samples. Clusters associated with holm-oak (groups A, C and D) comprise the majority of the *taxa* found (36 of the 48 identified) with 22 of them being exclusive of this site. In contrary, eucalyptus have only 12 species associated to it (clusters B and E), with just 5 species occurring only there.

Nodal analysis reflects not only the inter-site separation, but also a stratification inside each one of them. The highest constancy and fidelity values are associated with the upper soil layers, humus and pitfall samples, in detriment of mineral horizon. This preference is reflected not only in terms of species richness, but also in terms of abundance. From table 2 we can observe that humus layer and epigeic fauna possess the majority of the species and individuals. This is a quite common phenomenon and has been reported by several authors for different types of vegetation (Pozo and Martinez, 1983; Gama *et al.*, 1991; Mateos, 1992). In holm-oak forest this can be explained by the propitious characteristics the organic horizon can offer, promoted by the micro-climate stratification observed between horizons (*table* 1). However, in eucalyptus plantation, in the absence of such separation between strata, factors other than these must be responsible for this difference in richness. A similar impoverishment of mineral horizon in eucalyptus has already been pointed out by Gama *et al.* (1991).

The disruptions in the community composition can be partially attributed to changes in the soil surface environment derived from the establishment of the eucalyptus plantation. These changes, expressed by data in table 1, caused a decrease in microhabitat availability for springtails and then to a rupture in fauna structure. The existence of a conditioned litter layer is essential for decomposer microphytophagous animals like springtails, not only for food supply, but also for the microhabitat configuration they promote (specially the moisture conditions).

Other studies, where eucalyptus plantations are submitted to different forestry practices, are being undertaken and they will help us to interpret the results obtained here. Also complementary studies, analysing other variables, like the suitability of eucalyptus leaves as a food source and the decomposition and nutrient dynamics processes on eucalyptus plantations, are being implemented. With this dual approach we intend to get a more complete evaluation about the influence of this introduced species on the equilibrium of the soil system.

Table 2. – Total number of individuals of Collembolan species in coppices of holm-oak and eucalyptus plantations. Also diversity, evenness and species richness for the different strata on both sites.

Taxa	*Quercus rotundifolia*			*Eucalyptus globulus*		
	Humus	**Soil**	**Pitfall**	**Humus**	**Soil**	**Pitfall**
Hypogastrura affinis (Schäffer, 1900)	1		1			
Ceratophysella engadinensis (Gisin, 1949)	90	23	2	25	3	
Xenyllogastrura octoculata (Steiner, 1955)	8	2				
Microgastrura sensiliata (Jordana, 1981)			55			
Microgastrura duodecimoculata Stach, 1922	5					
Brachystomella parvula (Schäffer, 1896)	456	20	6	149	11	4
Friesea ladeiroi Gama, 1959	6	1				
Friesea steineri Simon, 1975	2					
Pseudachorutes parvulus Börner, 1901	11			9		
Pseudachorutes palmiensis Börner, 1903	1		1	2	2	
Anurida pusilla Gama, 1964				1		
Anurida sp.				1		
Superodontella carmenae Arbea et Lucianez, 1991				3		
Bilobella aurantiaca (Caroli, 1912)	1	2		15		
Neanura sp.	1					
Onychiurus gisini Haybach, 1960	149	7		29	9	
Onychiurus obsiones Cassagnau, 1963	4	2				
Mesaphorura macrochaeta Rusek, 1976	5	2				
Stenaphorura quadrispina Börner, 1901	5	8			1	
Isotomodes quadrisetosus Gama, 1963	3	6	1	1		
Proisotoma minuta (Tullberg, 1871)	97	6	3			
Proisotoma gisini Gama, 1964	18	5	1			
Cryptopygus scapelliferus (Gisin, 1955)	7	2				
Cryptopygus thermophilus (Axelson, 1900)	124	12		1		
Isotomiella minor (Schäffer, 1896)	9	12				
Isotomurus fucicola (Reuter, 1891)	75	1	21	11	1	
Isotomurus balteatus (Reuter, 1876)			8			1
Isotomurus palustris bimaculatus Agren, 1903 s. Stach, 1947			22			
Heteromurus major (Moniez, 1889)	2		7	2		4
Lepidocyrtus lusitanicus Gama, 1964	14	1	23			1
Lepidocyrtus sp.			3			55
Pseudosinella picta (Börner, 1903)	1			2		
Pseudosinella infrequens Gisin et Gama, 1969	4	1				
Pseudosinella sp. (3 + 3 eyes)				4		1
Entomobryidae juv.	10	6	3	3		5
Sminthurides parvulus (Krausbauer, 1898)	24		20			
Sphaeridia pumilis (Krausbauer, 1898)	27	1	23	2		
Sminthurinus aureus (Lubbock, 1862)	7					
Sminthurus multipunctatus Schäffer, 1896	3		33			6
Sminthurus sp.	14		3			
Allacma fusca (L., 1758)	2					
Caprainea bremondi (Delamare et Bassot, 1957)	3					
Dicyrtoma fusca (Lucas, 1842)			1			
Dicyrtomina ornata (Nicolet, 1841)						6
Dicyrtomina sp.			3	3		2
Arrhopalites caecus (Tullberg, 1871)		1				
Bourletiella gamae Bretfeld			1			14
Sminthuridae juv.	6	4	1			7
Number of Taxa	**35**	**22**	**23**	**18**	**6**	**12**
Total number of individuals	**1195**	**125**	**242**	**263**	**27**	**106**
Diversity (H′)	**3.24**	**3.79**	**3.56**	**2.38**	**2.04**	**2.47**
Evenness (E)	**0.63**	**0.85**	**0.79**	**0.57**	**0.79**	**0.69**
Richness (D)	**4.79**	**4.35**	**4.01**	**3.05**	**1.52**	**2.36**

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